

Fig. 2. Reproduction dynamics of *Spirodela* after 88-h exposure to the Skrunda Radio Location Station electromagnetic field. Plants aged 9, 28 and 52 h since germination, as well as free-growing uneven aged cultures, were exposed. Standard deviations (not shown) were low and did not exceed 5% of the mean values.

fronds (67 days compared to 86 days for the control) and lowered the total number of daughter per frond (7.8 fronds compared to 9.7 fronds in the control). For the fronds directly produced from the first mother, three deformed daughters per 100 mother turions were observed after 10 days, and 24 individuals with altered morphology per 100 mothers at 110 days. Of these morphologically different plants, eight had left symmetry, six

showed inverted geotropism and 10 had other deformities. In the control culture, only 1.6 individuals with deformed growth were seen at 110 days.

#### 4. Discussion

The experiments conducted on the effect of the Skrunda radio frequency electromagnetic field on

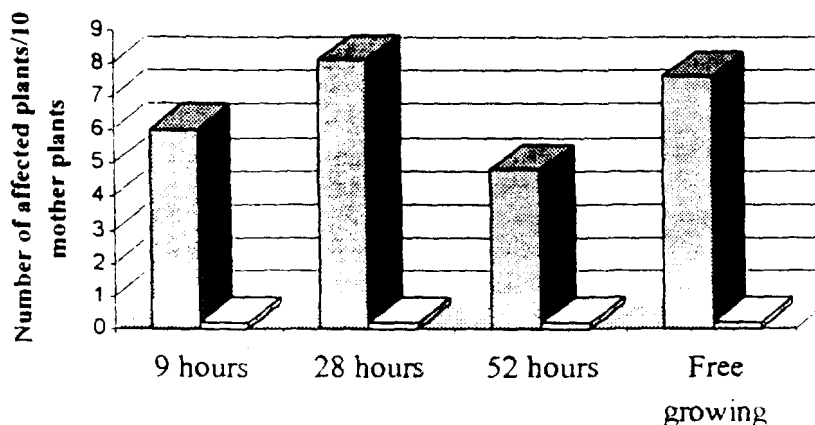


Fig. 3. Number of pathologies in next-generations of *Spirodela* plants after 88-h exposure to the Skrunda Radio Location Station electromagnetic field. Plants aged 9, 28 and 52 h since germination, as well as free-growing uneven aged cultures, were exposed. Shaded bars represent exposed plants and unshaded bars are the respective controls.

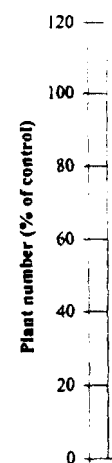


Fig. 4. Rate 120-h exposure to the Skrunda Radio Location Station electromagnetic field. Results are expressed as mean values and standard deviations are shown.

*Spirodela pectinifera* of short-term dependent on the electromagnetic fields observed [1] exposed to the Skrunda radio frequency electromagnetic field has been shown.

The decrease in the number of occurrences of pathologies 30 days after exposure to the Skrunda radio frequency electromagnetic field cause small deformities only after re-exposure. This is supported by the results of the experiments conducted to determine the number of individuals directly produced from the number of mother plants lower than in the control culture. In greater, since the geotropic changes in the descendants have been found in the plants on plan-

It has been

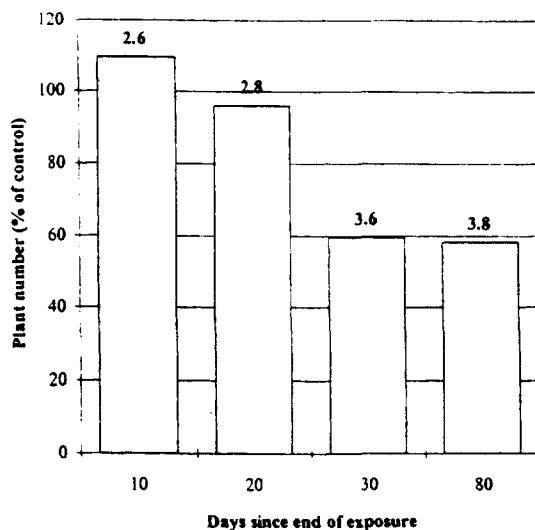


Fig. 4. Rate of vegetative reproduction of *Spirodela* after 120-h exposure to the Skrunda Radio Location Station electromagnetic field. Exposure began with turion germination. Results are expressed as percentages of the control. Standard deviations are given above the bars.

*Spirodela polyrhiza* clearly indicate that the effect of short-term exposure of up to 5 days is dependent on the stage of growth at time of exposure. The stimulation or repression of growth in magnetic fields of various intensities has been observed [11-13]. The growth rate of yeast cells exposed to radio frequency electromagnetic fields has been shown to be altered [14].

The decrease in reproduction rates and the occurrences of deformities in future generations 30 days after exposure indicate that the pulse-type Skrunda radio frequency electromagnetic fields cause small cellular changes that become evident only after replication in cell division. This is also supported by the fact that in the experiment to determine life span, where only the daughters directly produced from the mother were observed, the number of deformities was almost two times lower than in the case where all descendants were observed. In reality, this difference was even greater, since symmetrical inversions and geotropic changes were not counted when all descendants were observed. Similar effects have been found in the study of permanent magnetic fields on plants [13] and animals [15,16].

It has been suggested that species of the Lem-

naceae have characteristic developmental changes due to environmental impact [17]. The characteristic effects of the Skrunda Radio Location Station exposure changed geotropism (upward growing roots) and right left symmetry of development. The life span and number of future fronds of *Spirodela polyrhiza* decreased when the first frond had completely developed during radio frequency electromagnetic exposures at Skrunda. This type of hastened ageing has been observed in plants exposed to high intensity constant magnetic fields [13].

Our work suggests that studies of non-thermal radio frequency electromagnetic effects on organisms must be comparable to the life span of the organism. If short-term observations are made, only the organism response to electromagnetic radiation as a stress factor is seen. Long-term studies can yield different conclusions due to more effects becoming evident only at later times.

#### Acknowledgements

Much appreciation is extended to G. Brūmelis and D. Tjarve for technical help with the manuscript.

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#### Abstract

Previous bioassays of electromagnetic fields on animals for cytotoxicity and specific location of cows from a farm as an alternative to the applied. Microscopic red colour. The individual animals counting of micro and 0.1 per 100 distribution between

**Keywords:** Electromagnetic fields

#### 1. Introduction

It has been suggested that the effects of electromagnetic fields (EMF) on the Skrunda Radio Location Station (SRLS) have decreased (Magone et al., 1995). The exposure effects of EMF on the view of the Skrunda RLS, it

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## Measurement of the intensity of electromagnetic radiation from the Skrunda radio location station, Latvia

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### Abstract

This paper describes measurements of electromagnetic radiation intensity around the Skrunda Radio Location Station that were made in an attempt to provide the best possible data for biological effect studies, considering the available equipment and knowledge. The measured intensities fit expected patterns with distance from the source. The measured pulse intensities radiated by the Skrunda Radio Location Station (RLS) are considered to be more relevant for biologists. The variability of intensities is explained by radar mode, height and distance from source, and forest cover. While the pulse intensities are 50 times higher than allowed levels, the mean integrated intensities are lower than permitted.

**Keywords:** Radio location; Electromagnetic radiation; Pulse mode; Radar

### 1. Description of the Skrunda Radio Location Station 'Dnepr'

The Skrunda Radio Location Station (RLS) is a Dnepr-type, used for air defence to locate and track missiles and satellites. The station consists of two radars which operate in the 156–162 MHz frequency range. Each radar consists of a pair of long (250 m × 12 m) antennae that are slightly angled towards each other. One radar views a 60° sector (each antenna of the pair views a 30°

sector) centred at a 308° angle from North. The other views two 60° sectors, each oriented on either side of 308° direction, to angles of 263° and 353° from North (Fig. 1). Beam width to azimuth direction is 0.5°. In height, all sectors view from 5° to 35°. Station parameters which determine the intensity are:

Peak power of one antenna — 1.25 MW  
Peak duration — 0.8 ms  
Time between pulses (start to start) — 41 ms  
Antenna gain factor — 1800  
Mean power of one radar — 50 kW  
Radiation polarisation — horizontal

\* Corresponding author

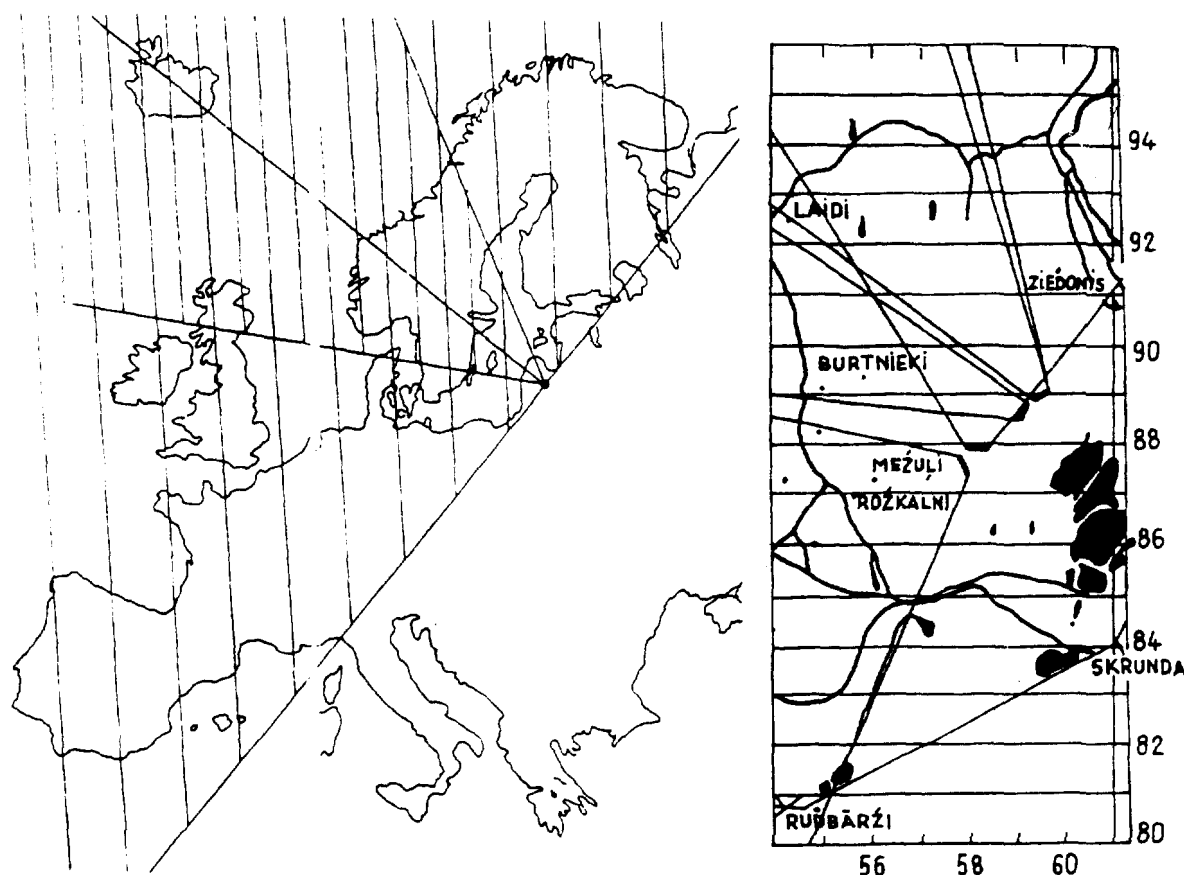


Fig. 1. Viewing area of the Skrunda Radio Location Station.

Frequency range (at  $-30$  dB) — 151–165 MHz

Three possible operating modes —

1. Fixed direction diagram
  - a. fixed central zone
  - b. fixed lower angle
2. Scanning mode
3. Tracking mode
  - a. central zone
  - b. lower angle

Within each operating mode, either the central zone or low angle type may be in use. The low angle type focuses radiation close to ground level by anti-phase connection of the antenna to divide it into two parts. The station parameters were supplied by V.L. Ardonovich, A.L. Minc Radio Technical Problems Institute, Moscow.

## 2. Measurement apparatus and methods

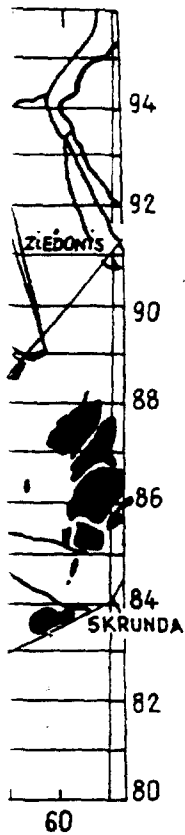
The measurement of electric field intensity was conducted in the Skrunda area seasonally and at different times of the day. However, continuous sampling was not possible at many locations. Initial measurements in 1990 were taken using the equipment P3-15, P3-17, SMV-8.5 and antenna P6-33 from Russia. Minimum values of measurement were less than or equal to 1 V/m. After these initial trials, most measurements were taken with a selective voltmeter STV-401 (Germany) and half-wave dipole antenna, which gave results between 1  $\mu$ V/m and 1 V/m. This apparatus first required locating the frequency with maximum intensity. To facilitate ease of measurement

collection, antennas at Skrunda Institute of Physics field intensity between 10  $\mu$ V/matus operates conducted using sine to calibrate sinusoidal radiographic record STV-401. The lower, due to n

The apparatus in a movement of the a ing site visits, entire area are available, with During the year visited 3–10 times the maximum visits were use



Fig. 2. Maximum and April 1993 at



## Methods

Electric field intensity was measured seasonally and at various locations. Initially, measurements were taken using the STV-401 and antenna measurements of maximum intensity were about 1 V/m. After calibration, measurements were taken using the STV-401 (Germany) which gave results with maximum accuracy.

collection, an apparatus suited to the requirements at Skrunda (the FI-1) was developed at the Institute of Physics, Latvia, which records electric field intensity in the 152- to 166-MHz band between 10  $\mu\text{V}/\text{m}$  and 20 V/m. Since this apparatus operates in pulse mode, calibration was conducted using pulse amplitude. It is more precise to calibrate with pulse amplitude rather than sinusoidal radiation. This was shown by oscillographic recording of a mechanical pointer-scale STV-401. The STV-401 measurements were 20% lower, due to mechanical pointer inertia.

The apparatus FI-1, which allowed measurement in a moving vehicle with appropriate orientation of the antenna, was used after 1992. During site visits, efforts were made to cover the entire area around the Skrunda RLS in the time available, with repeated visits to the same sites. During the years 1990–1994, most sites were revisited 3–10 times. In further analysis of results, the maximum intensities recorded during these visits were used. All equipment used were inter-

calibrated and they gave comparable results, fixing the root mean square (RMS) electric field intensity values.

An obvious drawback of the measurements that have been made was caused by the insufficient numbers of available apparatus that could be used for continuous measurement at some sites. At a distance of 2 km from the RLS, the device JA6P-109 was installed to make continuous measurements of maximum intensity during specific time intervals. Between readings, the apparatus stores the maximum RMS intensity in memory. Readings were taken about five times daily.

## 3. Electromagnetic radiation intensities

### 3.1. Temporal changes

The measured mean electric field intensities at the continuous monitoring site 2 km from the Skrunda RLS are shown in Fig. 2. The minimum and maximum intensities were 6 dB and 26 dB (1

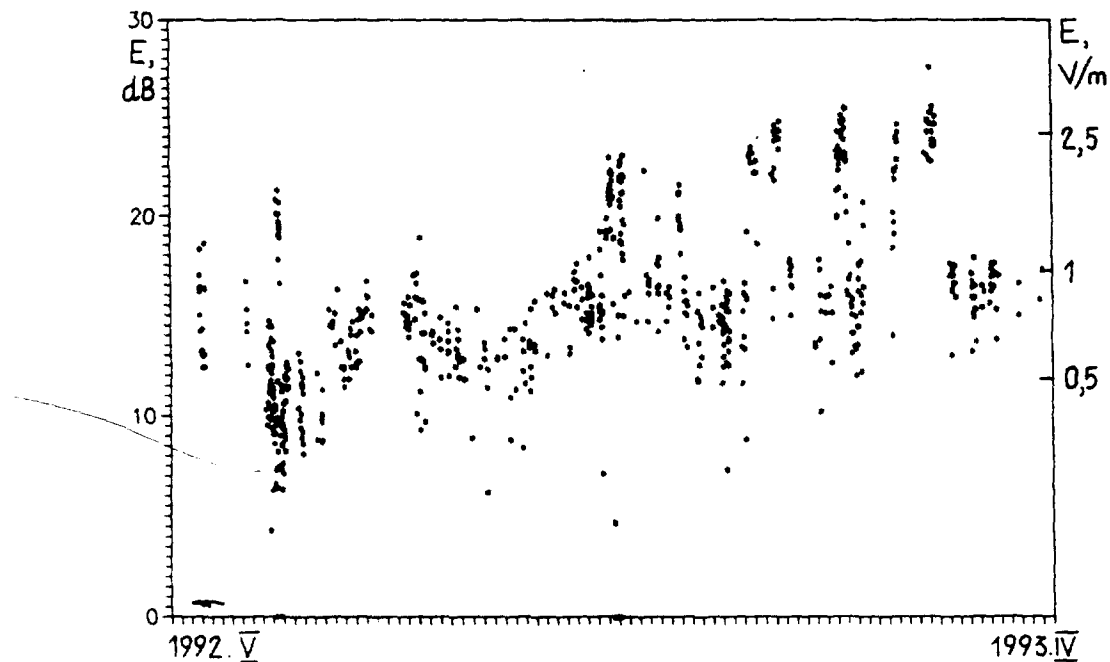


Fig. 2. Maximum RMS electric field intensities ( $E$ ) of electromagnetic radiation 2 km from the Skrunda RLS between May 1992 and April 1993 at height 1.5 m above ground level.

dB = 0.1 V/m), respectively. The large variation is due to the various operating modes, season, meteorological conditions, interaction with vegetation and other factors. The mean yearly root mean square (RMS) intensity (15.3 dB) and its confidence interval were derived using the Chebyshev inequality, due to a non-normal intensity frequency distribution curve. The precision of the measurements was better than 10%, since the sample size was high. It can be assumed that in time along all points within a beam, the relative temporal changes in intensity are similar. However, there are four beams but only one apparatus for continuous measurement. Nevertheless, it is likely that the overall variation pattern is similar for all beams.

### 3.2. Spatial changes

#### 3.2.1. Vertical changes

At ground level  $h = 0$ , the electric field intensity is zero. This is true theoretically and confirmed by measurement. The relationship between height and intensity is shown in Fig. 3a and 3b. Intensity changes as a square root function with height, i.e. the intensities stabilise with height. Stable intensities are achieved near the RLS at existing tree canopy levels, but are reached at much higher distances above ground level at dis-

tant locations. Thus, measurements at tree canopy level are predicted to be most meaningful for the assessment of effect, if trees are the studied organisms.

#### 3.2.2. Horizontal changes

The maximum electric field intensities measured at sampling locations around the Skrunda RLS clearly decrease with distance from the source (Fig. 4). The trend with distance is similar to curves calculated from radar radiation theory and data obtained from personnel responsible for the development and operation of the Skrunda RLS (mostly as unpublished documents of the A.L. Minc Radio Technical Problem Institute, Moscow) as follows.

Radiation power density ( $\text{kW}/\text{cm}^2$ ) in the direction of the main beam is shown in Fig. 5, determined by

$$P_o(R) = \frac{2.5 \times 10^5}{R} \quad (1)$$

where  $R$  is distance (m). The measurements taken in the Skrunda area were in the transition between near-field and far-field zones. Eq. 1 is an approximation of the true empirical formula for the transition zone, given in Fig. 5. Power density changes in relation to height are calculated by the

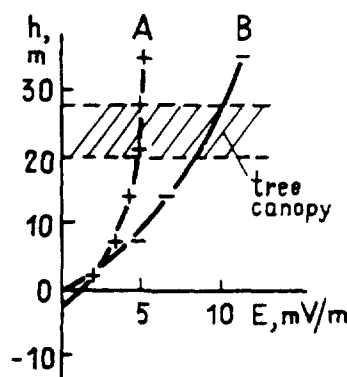


Fig. 3. Relationship between RMS electric field intensity and height at various locations around the Skrunda RLS. (A) 7.5 km in front of the radar; (B) 7.0 km behind the radar; (C) 6.4 km in front of the radar (forest); (D) 3.5 km in front of the radar (forest); (E) 3.5 km in front of the radar (field).

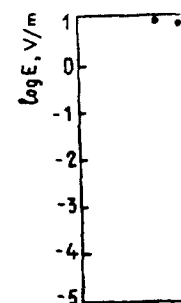
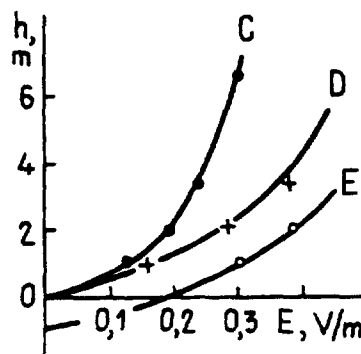


Fig. 4. Maximum height plotted against distance  $R$ . Curves are given. Curves 0.65, respectively. (with a P3-15, P3-1 or FI-1 apparatus).

experimentally

$$\delta(h) = \left( \frac{4 \times}{h} \right)$$

This equation range of height  $h$  (m).

The coefficient direction of the angle, is determined by the radar beam calculated to 1

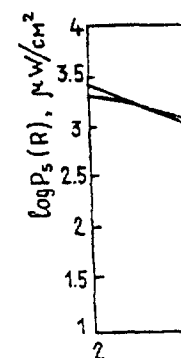


Fig. 5. Relationship between distance  $R$  to radar and log  $P_s(R)$ . Curves are given. Curves 0.65, respectively. (with a P3-15, P3-1 or FI-1 apparatus).

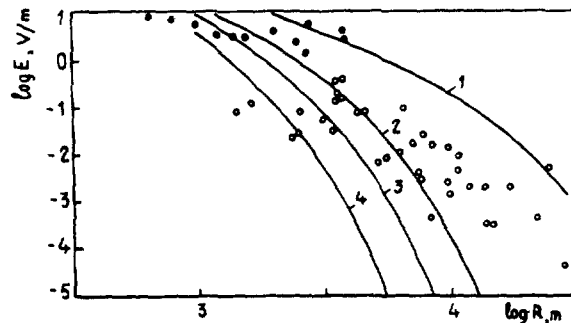


Fig. 4. Maximum RMS electric field intensity ( $E$ ) at a 2-m height plotted against distance from the Skrunda RLS. Theoretically derived curves for different forest cover  $k_m$  values are given. Curves 1–4 reflect  $k_m$  values of 0.05, 0.25, 0.4 and 0.65, respectively. Closed circles represent measurements made with a P3-15, P3-17 or SMV-8.5, and open circles with a STV or FI-1 apparatus.

experimentally derived diffraction factor,

$$\delta(h) = \left( \frac{4 \times \pi \times h \times H}{R \times \lambda} \right)^{0.5} \quad (2)$$

This equation is true for measurements in the range of heights of measurements made (up to 30 m).

The coefficient for angle correction to the main direction of the beam  $F(\gamma)$  where  $\gamma$  = beam angle, is determined from the antenna diagram of the radar beam in the low angle mode, and is calculated to be 0.34–0.35. The effect of forest

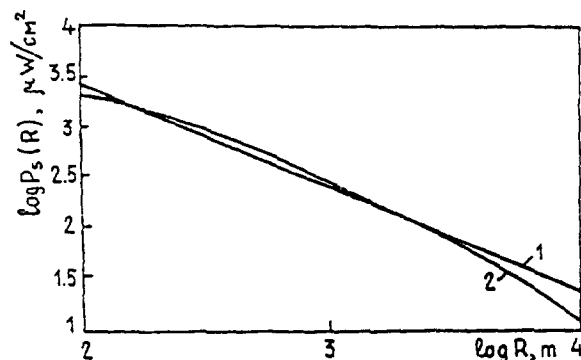


Fig. 5. Relationship between radiation power  $P_0(R)$  and distance  $R$  to radar along the trajectory of the main beam. 1, empirically derived; 2, curve obtained from the radar installation personnel.

cover on power density of radiation with horizontal polarisation is corrected for by the factor 0.03 dB/m [1]. Along a path with length  $R$ , where forests occupy a distance  $R_m$ , we obtain the coefficient

$$k_m = R_m/R \quad (4)$$

The loss in power density with distance then becomes

$$\beta(R) = 10^{-0.0015k_m R} \quad (5)$$

and the theoretical power density at a given distance is

$$P(R) = P_0(R) * \delta(h) * F(\gamma) * \beta(R) \quad (6)$$

To obtain the value of the electric field intensity in V/m, the relation  $P(R) = E^2/3.67$  may be used. Here  $P(R)$  is in kW/cm<sup>2</sup>.

In Fig. 4, the theoretical curves 1–4 reflect various input parameters: (1)  $k_m = 0.05$  (5% forest cover), (2)  $k_m = 0.25$  (25% forest cover); (3)  $k_m = 0.4$  (forest cover 40%) and (4)  $k_m = 0.65$  (65% forest cover). Clearly, the measured results fit the pattern of the theoretical curves. However, the existing forest cover in front of the Skrunda RLS range from 25% to 65%. Substitution of these values into Eq. 5 results in some intensities that are lower than those measured. This may be explained by a low correction factor for tree cover, that is not suited to the forest types present, height, density, and seasonal conditions. Also, the measurement locations are on a slope exposed to the RLS, which results in higher intensities than the horizontal case. The measured intensities fit  $k_m$  values between 0.05 and 0.4.

At all locations of homes in front of the RLS, the mean integrated electric field intensities at 2 m height did not exceed the allowed levels of 10  $\mu\text{W}/\text{cm}^2$  (6.13 V/m) used in the previous Soviet Union [2] or the IEEE maximal permissible exposures in controlled or uncontrolled environments [3]. If we use only the allowed levels as criteria, then we can conclude that there is no problem

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RLS. (A) 7.5 km in  
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from the RLS. However, the RLS radiates pulses of radiation at levels 50 times higher than the mean integrated allowed levels. Pulse duration is 0.8 ms, and during each pulse, there are 120 000 oscillations.

#### Acknowledgements

We express thanks to G. Brumelis for the translation and to J. Zvagulis for measurements of intensity. The comments of K. Laukkanen, G. D'Inzeo and an anonymous reviewer greatly helped to improve the text.

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#### Abstract

The Skrunda Ra a unique area for effects. Since 1990 control areas. The statistically significant the intensity of the electromagnetic radiation from the Skrunda RLS. environmental and

**Keywords:** Radio-f

#### 1. Introduction

The question of (RF) electromagnetic radiation to divide research into scientific camps. If living organisms are affected. Thus, the most effective action must be chosen required.

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0048-9697/96/\$15.00  
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## Brief Communication

# B16 Melanoma Development in Black Mice Exposed to Low-Level Microwave Radiation

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The effect of low-level microwave exposure, 2,450 MHz, at a power density of 1 mW/cm<sup>2</sup> and specific absorption rate of 1.2 mW/g, continuous waves (CW) or pulsed waves (PW): 2.5 h/day, 6 sessions/week until death (up to 690 h of irradiation), has been studied in black C57/6J mice with B16 melanoma. The results show that no significant effects are observed on tumor development or on survival times compared to controls, or between CW- and PW-treated animals.

**Key words:** melanoma, pulsed wave, continuous wave

Microwave hyperthermia has been used to treat tumors [Hiraoka et al., 1984; Santini et al., 1986]. Mutagenic and carcinogenic effects of microwave have been described in vitro and in vivo [Szmigielski et al., 1980]. In an epidemiological study, Milham [1982] has shown a possible relation between microwave exposure and cancer development. Robinette et al. [1980] failed to see such a correlation. The purpose of this work was to determine if prior low-level microwave exposition (CW or PW) has any effect on the development of B16 melanoma or survival times of black mice.

Forty-five 5-week-old female C57BL/6J mice were used. Three lots of 15 mice each were randomised into three groups: 1) controls; 2) exposed to CW microwave (1 mW/cm<sup>2</sup>); 3) exposed to PW microwave (1 mW/cm<sup>2</sup>), 10-ms duration of a burst of spikes, 30 ms between 2 bursts of spikes, 10-μs spike duration, 5 μs between 2 spikes.

Microwave irradiation was applied with a 200-W, 2,450-MHz source (Philips YJ 1510 à magnetron). Animals were irradiated 2.5 h/day, 6 sessions/week until death (up to 690 h), in the far field in an anechoic chamber 170 cm long, 60 cm wide, and 105 cm high. During microwave exposure the animals were placed in a polystyrene cage 25 cm long, 16 cm wide, and 13 cm high. The intensity of microwave was

Received for review January 20, 1987; revision received June 27, 1987.

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measured with a Narda Model 8221 meter. The electric field, E, was parallel to the length of the polystyrene cage.

Specific absorption rate (SAR), determined by the methods described by Gandhi [1979] and Durney et al. [1979], was about 1.2 mW/g. Controls were put in the anechoic chamber in the same polystyrene cages as exposed animals for 2.5 h without microwave exposure. To control for possible circadian rhythm effects, groups 2 and 3 were alternatively subjected to microwaves in the morning one day and in the afternoon on the next day (the same rotation was used for controls). Ambient temperature during exposure was  $20 \pm 2^\circ\text{C}$ . Animals in groups 2 and 3 were subjected to microwaves 15 days before melanoma cells were implanted. Subsequently, the 3 groups were implanted subcutaneously with  $3 \times 10^6$  melanoma cells (0.1 ml) using a technique described elsewhere [Voulot et al., 1985]. Microwave irradiation was continued for groups 2 and 3 until death of all mice within the groups. Two dimensions of tumor surface ( $\text{mm}^2$ ) were determined by measurement with a gauge measuring the largest diameter of the tumor and a second measurement at right angles to the first. Statistical analyses of results were done by use of three different tests:

- 1) Mean  $\pm$  standard deviations (SD) of the tumor surfaces during tumor development were compared with the use of the Student t-test.
- 2) The numbers of surviving animals and dead animals in the three groups were compared using  $\chi^2$  tests.
- 3) Survival times of animals were compared with the Wilcoxon-Mann-Whitney U-tests.

Figure 1 shows that B16 melanoma development was not significantly modified in microwave exposure in group 2 or group 3. Also, there were no differences in

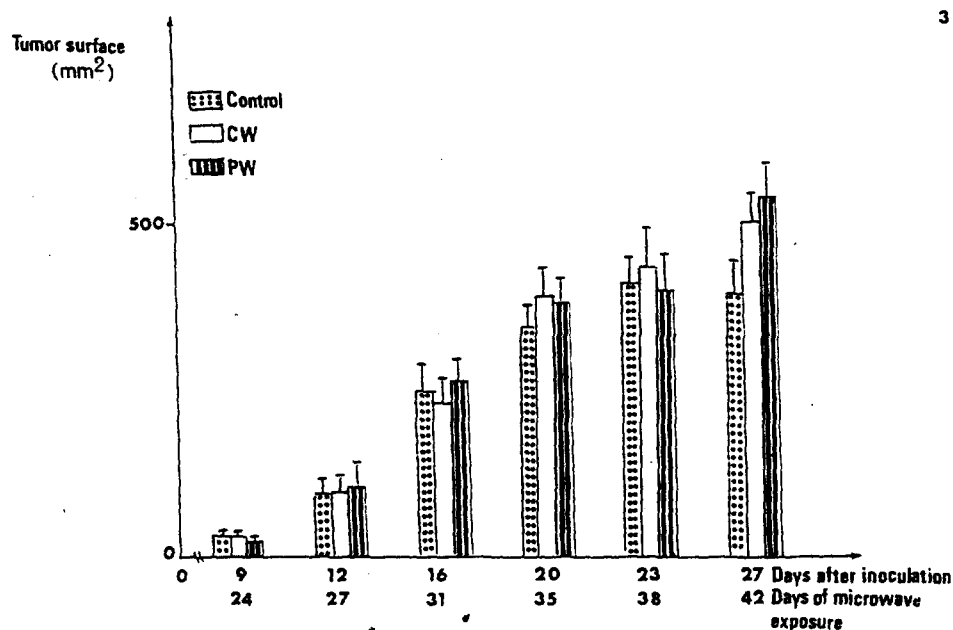


Fig. 1. Effect of low-level microwave exposure (2,450 MHz, SAR = 1.2 mW/g) on development of B16 melanoma in C57 BL/6J (mean tumor surface- $\text{mm}^2 \pm$  standard error of the mean).

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TABLE 1. Mean Survival Times (Days  $\pm$  SD) of Mice Bearing B16 Melanomas Exposed to Low-Level Microwaves (2,450 MHz, SAR = 1.2 mW/g)

	Average survival time (days $\pm$ SD)
Group 1 = control	25.9 $\pm$ 6.2
Group 2 = exposed to continuous waves	24.4 $\pm$ 7.9
Group 3 = exposed to pulsed waves	26.6 $\pm$ 8.5

survival between CW- and PW-treated animals or controls. Table 1 shows mean survival times ( $\pm$  SD). Analysis of all individual survival times with the Wilcoxon-Mann-Whitney U-test showed no significant differences between the three groups.

Some studies have shown PW microwave exposure to have biological effects different than those of CW [Seaman and Wachtel, 1978]. This study fails to show such a difference. Exposure to low-level microwaves before tumor implantation did not significantly affect tumor development or survival times of animals with B16 melanomas. Acceleration of cancer development observed in mice by microwave irradiation by Szmigielski et al. [1980] was not observed in this study. The lower incident power density used in the study may account for the failure to see any effect.

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The Science of the Total Environment 180 (1996) 3-8

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## Epidemiological studies of radio-frequency radiation: current status and areas of concern

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### Abstract

These comments deal with the possible impact on human populations of intense sources of radio-frequency radiation, and not the much lower level of the usual sources of such radiation associated, for example with household appliances. These intense sources were developed and extensively used first in World War II (1940-45). Much of the health evaluation has been done by, and for, military organizations. There are important differences in the energy generated by low frequency (ELF) and radar; it then follows that there may be differences in their effects on human populations. Problems common to both types are: (1) the uncertainty as to biological mechanisms; (2) weak experimental evidence of effect; (3) epidemiological preoccupation with carcinogenesis, with its latency and low incidence. For both types there is the presumption of greater occupational than community risk, the latter often not well studied, and problems as to exposure quantification and specificity. To these one must add (4) the inherently epidemiological problems of a study at a given source of adequate sample size, case-findings, exposure estimation, confounders, and residential and job instability. Despite these problems, there are findings from sets of studies which suggest four possible health effects from radar (radio-frequency radiation) exposure: (A) disturbances in blood counts, not necessarily of clinical severity; (B) changes in chromosomes of white blood cells; (C) increases in frequency of unfavorable reproductive outcomes, especially spontaneous abortion, and (D) increases in cancers of certain sites. A review article on this topic was published (although after the Skrunda meeting) [6] providing evidence from various exposures on such possible effects. A brief critique is provided of evidence on these four possible effects, identifying some areas of uncertainty for which studies at sites like Skrunda could provide useful information.

**Keywords:** Radio-frequency radiation, health effects; Microwave radiation, health effects; Radar, health effects; Epidemiological studies

### 1. Introduction

Human population risks from radar exposures have been part of the military, navigational and intelligence experience of World War II and the Cold War. Steneck et al. [1] provide a historical review of the origins of U.S. safety standards for microwave radiation, which documents the early findings, and how they affected protective mea-

asures. It also introduces the controversial issue of whether tissue heating (thermal effects) should be the principal basis for health protection, based as it is on short-term reactions, or whether there are long-term effects, which may occur independently of thermal effects, and usually at a lower rate of exposure.

In an editorial, the British Medical Journal [2] called concern about microwaves 'emitted from

electronic devices, including diathermy units, heating devices, television receivers, communication radar units and some domestic ovens' a 'paper tiger', citing Eisenbud's review in the Bulletin of the New York Academy of Medicine [3]. The editorial concluded 'At present, the evidence on microwave devices is that — if properly used — they are safe. Clearly, however surveillance should continue, including detailed epidemiological investigations.'

We do not refer here to 'devices', but to large-scale sources, with the possible exception of devices used for physiotherapy treatment. Even physiotherapy hazards, if present, are to therapists repeatedly exposed and not to the persons receiving the therapy.

Officials who design protective regulations, most of whom have an engineering rather than a medical background are often selected on the basis of their military or governmental experience. The ease of quantification and the lack of ambiguity of thermal effects, as compared to the relative weakness and apparent inconsistency of some non-thermal effects can be readily used to justify dependence of regulations on thermal effects. Goldsmith [4] reviews some of these problems in discussing the role of epidemiology in radiation health protection. We must expect, given the relative scarcity of experimental work, for example, on mutational consequences of exposure to non-ionizing radiation as contrasted with that for ionizing radiation, that the level of scepticism for the epidemiological findings of non-ionizing radiation would be greater than for ionizing radiation.

## 2. Hematological effects

A hematological study of U.S. State Department employees working in the Moscow Embassy and irradiated by Soviet sources was reported to the Government on 7 October 1976 by Tonascia and Tonascia [5]. Among their findings were that comparing the tests for Moscow-based employees with data from Foreign Service examinations done in Washington DC, 'The differences between the two groups with respect to every parameter except monocytes (% and counts) are highly statisti-

cally significant ( $P < 0.001$ ) after appropriate transformation'. Specifically, the Moscow group had a higher mean hematocrit, and a lower neutrophil percentage, but higher percentages for the other three cell types (lymphocytes, eosinophils and monocytes). The white cell counts are strikingly higher in the Moscow group. Several statistically significant changes over time occurred in the Moscow group; specifically, mean hematocrit increased and a threefold increase in monocyte count occurred. Neutrophil percentages fell and then rose and the reverse pattern was seen for the lymphocytes. Changes over time were also occurring in exposures, but they were not easily quantified. The purpose of this irradiation is not entirely clear, nor is it clear that other embassies in Eastern Europe were not irradiated.

These data were based on samples taken in two different places, and analyzed, we assume, by different laboratories. The changes are in any event within clinical bounds, that is no frank anemia or other disease was found. Goldoni and colleagues have conducted periodical examinations of the blood counts of 35 air traffic controllers, who use radar to assist in identifying the position of incoming and outgoing aircraft in Zagreb (Croatia) airport [7]. The estimated exposures ranged from 10  $\mu$ W to 20 mW in a frequency range of 1250-1350 MHz. The numbers of leukocytes and erythrocytes was significantly lower in the radar-exposed technicians. With repeated exposures, progressive or cumulative changes occurred, but also within the limits usually used for normal findings.

## 3. Carcinogenesis and mutagenesis

### 3.1. Moscow (U.S.) Foreign Service workers' study

About one-half of the persons working at the embassy tested for chromosomal abnormalities showed sufficient evidence of damage so that clinical guidelines would have had them restricted from reproductive activity until the abnormality had been shown to have been abated [6].

A large-scale epidemiological study of the Moscow Foreign Service workers and dependents was undertaken by a team headed by Professor

Lilienfeld for most important of which was not certain the comparison. The occurrence more frequently (1.33 suspected 1.02. Survey). Lilienfeld additional for the latency had been insufficient 20 years) for result from follow-up, as increase in leukemia. Moscow staff the comparison occurred compared.

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### 3.2. Cancer studies

A series of 1 workers exposed assembled by total leukemia exposed, with and especially of the studies mortality. The tional group (2. was found for

Lilienfeld from Johns Hopkins University [8]. The most important comparison was with the residents of other East European embassies, but it was not certain whether microwave exposures of the comparison group could also have occurred. The occurrence of multiple site cancers was far more frequent than in any other population studied (1.33 sites per person, compared to the expected 1.02, based on the Third National Cancer Survey). Lilienfeld strongly recommended that additional follow-up studies be undertaken, since the latency period for some types of cancer had been insufficient (usually requires a minimum of 20 years) for cancer to occur if indeed it was to result from the exposures. There has been no follow-up, as far as is known. There was an increase in leukemia, two deaths observed in the Moscow staff, when 0.8 cases were expected. In the comparison embassies, three leukemia deaths occurred compared to 1.7 expected.

There were four deaths from cancer of the female genitalia compared to 0.8 expected. In other comparison embassies, there were three such deaths compared to 1.3 expected. Four dependent children died of cancer among Moscow-employed families compared to 1.5 expected.

Such findings are consistent with excess cancer incidence in both the Moscow embassy and in other Eastern European embassy employees, but the latter group was being treated as the reference population, which if the supposition that they had also been irradiated were valid, would assure a spuriously negative finding.

The estimated exposures in Moscow varied from a maximum of  $5\text{--}18 \mu\text{W}/\text{cm}^2$  at various times.

### 3.2. Cancer studies in electrical workers

A series of 11 occupational mortality studies of workers exposed to electromagnetic fields was assembled by Savitz and Calle [9]. Results for total leukemia show a modest excess risk for men exposed, with enhanced risk for acute leukemia and especially acute myelogenous leukemia. Three of the studies were of incidence and eight of mortality. The highest risk ratio for any occupational group (2.6) for acute myelogenous leukemia was found for telegraph, radio and radar opera-

tors (95% confidence limits were 1.4–4.4). For greater detail see Goldsmith [6].

Milham [10] examined mortality data for amateur radio operators in California and Washington from 1979 through 1984, based on the current license file of Federal Communications Commission. Excess leukemia was practically confined to the operators in California, since in Washington there were five deaths compared to 4.7 expected. In California, 31 leukemia deaths were reported compared to 24.3 expected, and for tumors of other lymphatic tissues, 38 were observed compared to 22.3 expected, a significant increase. Again, the highest risk was for acute myelogenous leukemia, with 15 cases observed compared to 8.5 expected. Milham suggested that about 1/3 of the amateur radio operators were also occupationally exposed. It is estimated that amateur radio operators spend about 6 h a week at their hobby, so it is reasonable to consider these data as reflecting something between an occupational and a community exposure.

The variety of frequencies and lack of standardized observations of exposure and the mixed nature of many exposures make it difficult to attribute a single type of finding to exposure to radar. While doses can be estimated for some of the exposures, no generalisation of dose or of exposure can be made.

### 3.3. U.S. Navy radar personnel study

Robinette, Silverman and Jablon report [11] on 'Effects on Health of Occupational Exposure to Microwave Radiation (Radar)'. Mortality by cause of death, hospitalization during service, later VA (U.S. Veterans Administration) hospitalization and VA disability were examined for about 40 000 enlisted naval personnel who served during the Korean War, 1950–1954. Although the abstract gives a global negative statement 'No adverse effects were detected in these indexes that could be attributed to potential microwave radiation exposures during the period 1950–1954' some of the data in the article are strongly suggestive of such adverse effects. Although some of the differences do not reach customary levels of significance (they could be found by chance about once

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in 10 samples), they nevertheless are also consistent with almost two times as much lymphatic and hematopoietic cancer in the high exposed compared to the low exposed group. Exposure was to radar used for communication, detection of hostile activity, and associated with missile and ordnance firing. The article uses a job classification based on equipment maintenance and repair as a highly exposed group, compared with those job classes using the equipment.

The group estimated to have the highest exposure has a significantly elevated rate of leukemia, but is lumped with the next highest group, and together these two do not have a significant excess of leukemia. The study should not be considered to have negative results.

#### 3.4. Study of broadcast facilities and adjacent population in Hawaii

##### 3.4.1. Honolulu broadcasting towers

A unique opportunity to study the cancer incidence in the vicinity of radio broadcasting towers occurred in Honolulu, in part because the hills surrounding the town are a nature reserve and so the towers are located in many of the populated census tracts of the city.

Anderson and Henderson of the State Health Department took advantage of the State Cancer Registry to compare the cancer incidence of nine census tracts including broadcast towers with two demographically similar tracts without towers [13]. The U.S. Environmental Protection Agency measured RF radiation at 21 locations, and reported that public exposures at 12 of the locations exceeded currently recommended limits. At two outdoor sites, exposures were greater than  $1000 \mu\text{W}/\text{cm}^2$ , but in general at distances greater than 100-150 feet from the towers, the exposure levels were below  $100 \mu\text{W}/\text{cm}^2$ . EPA officials stated that RF radiation in Honolulu did not pose an immediate risk to the public. For leukemia, the Standardized Incidence Ratios (SIR) are 0.59 and 2.08 for tracts without and with broadcasting towers. Honolulu includes a substantial number of persons of Polynesian and Oriental origin. If then the data are adjusted by race, rather than by age, the SIR for total cancer for both sexes in tracts

without towers is 1.07, compared to 1.88 in the tracts with towers, the latter being significantly elevated. The authors point out that such an ecological design does not allow the establishment of a cause-effect relationship between cancer incidence and low levels of RF radiation, nor were there sufficient data to show a dose-response relationship. The study strongly indicates the need for more comprehensive studies and more powerful study designs.

##### 3.4.2. The childhood leukemia cluster on the Waianae Coast, Hawaii

In 1985, the Hawaii Department of Health was informed by a pediatric oncologist that he had seen an unusual number of children with leukemia in the small communities of the Waianae Coast. The area is the site of the Lualualei Naval Broadcast Facility. The leukemia excess was confirmed by the Hawaii Cancer Registry in 1986. In 1990, the Department conducted a more detailed investigation and a case-control study [14].

A case was defined as a child under 15 years of age, diagnosed with acute leukemia between 1977 and 1990 and who had spent at least 25% of his/her lifetime before diagnosis in the area. Fourteen cases met this definition, of whom 12 were permanent residents and two had spent 2-3 days a week in the area. Based on the State's cancer registry, the number to be expected was about one every 2 years or about seven cases in 14 years. Seven of the cases occurred during 3 years 1982-1984. After 1985, the incidence returned to the expected one, of a case every 2 years.

A relative risk of 3.5 (but not significant) was found for residing within 2.2 miles of one of the broadcast towers. The authors report that improper storage of oil may have been associated with a risk of benzene exposure, a known adult leukemogen. No adequate environmental measurements of radiation or of benzene exposure were available. Some measurements of electric or magnetic fields were made by the US EPA in 1990, but primarily along roads, and not where the children lived and played.

The authors conclude that '... closeness to the low frequency radio towers at Lualualei Naval

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Station may have a weak association with leukemia, even though it is not statistically significant. This cannot be considered proof that anything emanating from the station actually caused the leukemia.'

It is surprising that there are so few reported studies of possible health effects near broadcasting facilities. The often remote location of most such facilities and low measured values of supposed exposures, in the light of existing regulations, may be possible reasons.

#### 4. Reproductive outcomes

Ouellet-Hellstrom and Stewart reported on the frequency of miscarriages among female physiotherapists reported using radio- and microwave frequency electromagnetic radiation [12]. The exposure frequencies are 27.12 MHz for short-wave medical therapy and 915 MHz and 2450 MHz for microwave. In total, 42 403 members of the American Physical Therapy Association were queried as to pregnancy history and use of microwave or radio-frequency diathermy. It was possible to compare 1791 miscarriages with 12 949 'control' pregnancies in a nested case-control design.

Microwave exposure during pregnancy was significantly associated with spontaneous abortion. Exposures to radio-frequency diathermy did not show much effect.

The authors discuss a number of possible biases and concluded 'women who reported use of microwave diathermy at the time of conception were at increased risk of miscarriage. The risk increased with increasing exposure, and persisted even when known confounders were taken into consideration. Whether the excess risk is associated directly with the use of microwave diathermy per se or with something closely related to its use has yet to be determined. Women who reported using shortwave diathermy were not at increased risk.'

#### 5. Reflection of the evidence in regulations

The 'Guidelines on Limits of Exposure to Radio frequency Electromagnetic Fields in the Frequency Range from 100 kHz to 300 GHz, pre-

pared by the International Non-Ionizing Radiation Committee of the International Radiation Protection Association and published in 'Health Physics' in 1988 [15] was based on the 1981 review of biological effects compiled by UNEP/WHO/IRPA as Environmental Health Criteria 16 [16], and it provided the scientific rationale for interim guidelines published in 1984. In the guidelines the basic limits for exposure are expressed by the specific absorption rate (SAR, Heating effect) in units of Watts/kilogram. But for frequencies below about 10 MHz, SAR is noted to have limited usefulness, compared to current density generated in the body, which is estimated by the effective electric field strength and effective magnetic field strength,  $E_{eff}$  and  $H_{eff}$ , in units of V/m and A/m. In the rationale for the standards, it is stated that the SAR is a convenient quantity to assess biological effects which depend on the increase in temperature associated with RF absorption. While stating that: 'The emerging evidence for non-thermal mechanisms for biological effects cannot be ignored, and has to be considered in establishing exposure limits..', no quantitative relationships for non-thermal effects in humans are given, 'and the committee considered the recent data linking electric and magnetic field exposure to increased cancer risks of congenital anomalies in various human populations. Available data are inconclusive and cannot be used for establishing exposure limits.'

#### 6. Resume of possible effects to be considered

A. There is abundant evidence that hematological abnormalities were found early in the Moscow Embassy employees, and some evidence of effects in air traffic controllers and Naval personnel.

B. Chromosomal abnormality tests show that there were substantially increased frequencies of mutation in 18 out of 36 individuals exposed at the Moscow Embassy tested (including two with growth failure for the cultured cells).

C. A study finds that physiotherapists exposed to microwaves have substantially increased spontaneous abortion, while those exposed to short wave diathermy do not.

D. While cancer and leukemia may be increased in those sufficiently exposed to microwave radiation, it is a more prudent base for the protection of exposed persons if hematological or chromosomal reactions are used, since these indices can occur earlier and are reversible.

There are strong political and economic reasons for wanting there to be no health effects, just as there are strong public health reasons for more accurately portraying the risks.

There is no reason for epidemiology to be limited to its historical role of body-counting when there are more useful contributions to make as well. These include epidemiological studies of biological indicators of exposure and of risk, epidemiological study of hematological changes, (whether or not of clinical relevance), evidence for chromosomal effects, and study of reproductive outcomes in nominally high risk groups.

Such uses of epidemiology would be particularly useful in the Skrunda exposure situation for protection of the population from long-term risks, as well as for its potential contribution to our fund of knowledge needed for protecting other exposed populations, whose numbers are increasing. A similar approach to other such installations, such as the PAVE PAWS site on Cape Cod, would be of great interest.

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ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

VOLUME 247

February 28, 1975

BIOLOGIC EFFECTS OF NONIONIZING RADIATION\*

Editor and Conference Chairman

PAUL E. TYLER

CONTENTS

Preface By PAUL E. TYLER	5
Overview of Electromagnetic Radiation Research: Past, Present, and Future By PAUL E. TYLER	6
<b>Part I. Effects on the Nervous System</b>	
Introduction: Effects of Electromagnetic Radiation on the Nervous System By W. R. ADY	15
Biochemical and Neuroendocrine Aspects of Exposure to Microwaves By SOI M. MICHAELSON, WILLIAM M. HICK, NANCY J. A. LERDA, SHIN-TSU LU, AND RICHARD L. MAGIN	21
Effects of Low Intensity Microwaves on Isolated Neurons By HOWARD WACHTEL, RONALD SEAMAN, AND WILLIAM JOHNS	40
Some Effects of Electromagnetic Radiation on the Brain and Spinal Cord of Cats By EUGENE M. FAYER AND ROSS J. ADLERMAN	63
Effects of Modulated vhf Fields on the Central Nervous System By S. M. HAWIN, E. K. KAUZMAREK, AND W. R. ADY	74
Synchronization of Cortical Neurons by a Pulsed Microwave Field as Evidenced by Spectral Analysis of Electroencephalograms from the White Rat By B. SERVANTIE, A. M. SERVANTIE, AND J. LIESEN	82
Do Microwaves Alter Nervous System Structure? By ERNEST N. ALBERT AND MARK DE SANTIS	87
Experimental Morphologic and Electroencephalographic Studies of Microwave Effects on the Nervous System By S. BARANSKI AND Z. LUDWIG	109
Possible Physical Substrates for the Interaction of Electromagnetic Fields with Biologic Membranes By IRVIN I. GROSSKY	117
<b>Part II. Effects on Special Senses</b>	
Investigation of Single-Exposure Microwave Ocular Effects at 3000 MHz By BUDD APPLETON, STUART E. HIRSCH, AND PETER V. K. BROWN	125
Screening for Cataracts among Veteran Radar Repair and Maintenance Technicians By R. D. McAFEE, L. L. CAZENAVETTE, AND M. G. HOLLAND	135
Use of a Dielectric Lens for Experimental Microwave Irradiation of the Eye By R. L. CARPENTER, G. L. HAGAN, AND E. S. FERRE	142
The Ocular Effects of Microwaves on Hypothermic Rabbits: A Study of Microwave Cataractogenic Mechanisms By PIRO O. KRAMAR, ASHLEY F. EMERY, ARTHUR W. GUY, AND JAMES C. LIN	155
Ultrastructural Changes in the Rabbit Lens Induced by Microwave Radiation By RANDAL J. WILLIAMS, ADAM MCKEE, AND EDWARD D. FINCH	166
Ascorbic Acid Changes in Cultured Rabbit Lenses After Microwave Irradiation By J. J. WEITPR, E. D. FINCH, W. SCHULTZ, AND V. FRATTALI	175
Detection of Weak Electromagnetic Radiation by the Mammalian Vestibulocochlear Apparatus By ROBERT M. LEROWITZ	182

\*This series of papers is the result of a conference entitled *Biologic Effects of Nonionizing Radiation*, held by The New York Academy of Sciences on February 12, 13, 14, and 15, 1974.

E179

Biologic Effects of Nonionizing Radiation

Microwave-Induced Acoustic Effects in Mammalian Auditory Systems and Physical Materials. By ARTHUR W. GUY, G. K. CHOU, JAMES C. LIN, AND D. CHRISTENSEN	194
Action of Corti's Organ and the Cochlea: A New Theory. By JOHN E. MALCOLM	219

#### Part III. Biochemical and Biophysical Effects

Microwave Effects on the Blood-Forming System with Particular Reference to the Lymphocyte. By PRZEMYSŁAW CZERSKI	232
The Effect of Electromagnetic Radiation on the Hematopoietic Stem Cells of Mice. By D. ROTKOVSKÁ AND A. VACEK	243
The Effect of Microwaves (2450 MHz) on Isolated Rat Liver Mitochondria. By JOE A. ELDER AND JOSEPH S. ALI	251
Effect of Microwaves on Cell Function and Virus Replication in Cell Cultures Irradiated <i>In Vitro</i> . By S. SZMIGIELSKI, M. LUCZAK, AND MARZENA WIRANOWSKA	263
Effect of 10-cm (3 GHz) Electromagnetic Radiation (Microwaves) on Granulocytes <i>In Vitro</i> . By STANISŁAW SZMIGIELSKI	275
A Comparison of Thermal and Radio-frequency Exposure Effects on Trace Metal Content of Blood Plasma and Liver Cell Fractions of Rodents. By T. RUPP, J. MONTEF, AND J. W. FRAZER	282
Effects of Electromagnetic Fields on Microsomal ATPase and Mitochondrial Oxidative Phosphorylation. By K. D. STRAL AND P. CARVER	292
Effects of Microwave Radiation on Enzymes. By E. K. YEAGER, J. B. LANGLEY, A. P. SHEPPARD, AND G. K. HUDDLESTON	301
Acute Staphylococcal Infections in Rabbits Irradiated with 3-GHz Microwaves. By S. SZMIGIELSKI, J. JEJAZEWICZ, AND MARZENA WIRANOWSKA	305
Discussion Paper: Irradiation of Bovine Serum Albumin with a Crossed Beam Exposure-Detection System. By JOHN W. ALLEN	312
Discussion Paper: Raman Spectroscopy of Molecular Species During Exposure to 100-MHz Radio-Frequency Fields. By STANLEY M. KLAINER AND JAMES W. FRAZER	323

#### Part IV. Effects on Genetics and Development

Genetic Continuity and Metabolic Regulation as Seen by the Effects of Various Microwave and Black Light Frequencies on these Phenomena. By SYDNEY J. WEBB	327
Effects of Nonionizing Electromagnetic Radiation on Single-Cell Biologic Systems. By C. F. BLACKMAN, S. G. BENANE, C. M. WEIL, AND J. S. ALI	352
Effects of Electromagnetic Radiation on Implantation and Intrauterine Development of the Rat. By F. DIETZEL	367
Some Effects of Exposure of the Japanese Quail Embryo to 245-GHz Microwave Radiation. By DONALD I. McREE, PHILIP F. HAMRICK, JOSEPH ZINKL, PAUL THARTON, AND CARMEN R. PARKHURST	377
Effects of Electromagnetic Fields on Fecundity in the Chicken. By W. E. KRUGER, A. J. GIAROLA, J. W. BRADLEY, AND A. SHIRKENHAMER	391
Threshold Effects of Microwave Radiation on Embryo Cell Systems. By S. D. PYLE, D. NICHOLS, F. S. BARNES, AND F. GAMOW	401

#### Part V. Effects on Behavior

Introduction: Effects on Behavior. By D. R. JUSTESEN	408
Microwave Dose-Response Relationships on Two Behavioral Tasks. By W. D. GALLOWAY	410
Preliminary Investigations of the Effects of Low Level Microwave Radiation on Spontaneous Motor Activity in Rats. By B. ROBERTI, G. H. HEERELS, J. C. M. HENDRICK, A. H. A. M. DE GREEFF, AND O. L. WOLTHUIS	417

Effects of Low Level Microwave Radiation on Behavioral Baselines. By JOHN R. THOMAS, EDWARD D. FINCH, DAVID W. TULEK, AND LINDA S. BURCH	425
Neural Function and Behavior: Defining the Relationship. By ALLAN H. FREY, SONDRA R. FRED, AND BARBARA FREY	433
Behavioral Effects of Pulsed Microwave Radiation. By EDWARD I. HUNT, NANCY W. KING, AND RICHARD D. PHILLIPS	440

#### Part VI. Dosimetry

Contrast of Dose Distribution in Phantom Heads due to Aperture and Plane Wave Sources. By HENRY S. HO	454
Microwave Energy Distribution Measurements in Proximity to Man and Their Practical Application. By D. E. BRISCHER AND V. R. RENO	473
A Miniature Broad-Band Electric Field Probe. By H. BAYEN, M. SWICORD, AND J. ABITA	481
Measurements of Power Absorption by Human Phantoms Immersed in Radio-frequency Fields. By STEWART J. ALLEN	494
Field Measurements, Absorbed Dose, and Biologic Dosimetry of Microwaves. By RICHARD D. PHILLIPS, EDWARD I. HUNT, AND NANCY W. KING	499
A Pyroelectric Probe for Measurement of Microwave Power Density under Far-Field Conditions. By G. K. HUDDLESTON AND D. I. McREE	510
Discussion Paper: Fiberoptic Liquid Crystal Probe for Absorbed Radio-frequency Power Temperature Measurement in Tissue During Irradiation. By CURTIS C. JOHNSON, CARL H. DURNFY, JAMES T. LORIS, AND GORDON K. LIVINGSTON	527
Discussion Paper: Strong Dependence of Whole Animal Absorption on Polarization and Frequency of Radio-frequency Energy. By O. P. GANDHI	532
Future Research Directions and Needs in Biologic Electromagnetic Radiation Research. By ARTHUR W. GUY	539

This monograph was aided by a contribution from:

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microwave source or by conventional methods. The experiment was repeated for different final temperatures for both lysozyme and trypsin. Although small apparent variations in the activity of the enzymes exist due to the heating method, when analyzed by standard techniques, the differences are not significant.

When the results of an experiment such as this indicate no significant difference between the experiment and control, it is often a source of more concern than if one had been observed. In this case, however, careful control of the experiment process and the small variability observed in the results of more than 50 independent measurements on the two enzymes lends confidence to the conclusion that indeed no differences in enzyme performance were observed as a function of the heating methods, either by microwaves or by a coil.

The relative ease with which this technique allows investigation of the sensitivity of organic compound solutions to microwave-induced heating has prompted interest in studying other enzymes with the same method. In particular, the enzyme cholinesterase, which is involved in interneuron impulse transmission, is of interest, because a sensitivity of this enzyme to damage by microwave energy could help explain some of the reported neurologic phenomena for which a satisfactory theory has not been posed.

#### DISCUSSION

DR. S. F. CLEARY (*Medical College of Virginia, Richmond, Va.*): At what wavelength did you perform your experiment?

DR. YEARGERS: 12.5 cm.

DR. CLEARY: Do you plan to examine the entire spectrum of frequencies rather than just one?

DR. YEARGERS: Yes.

DR. FLORES (*University of Utah, Salt Lake City, Utah*): At the same temperature, did you find the same loss of activity for both enzymes?

DR. YEARGERS: No. Lysozyme is slightly more heat resistant.

## ACUTE STAPHYLOCOCCAL INFECTIONS IN RABBITS IRRADIATED WITH 3-GHz MICROWAVES\*

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Long-term exposure of animals to thermal and nonthermal power densities of microwave radiation disturbs the hematopoietic system and alters peripheral blood cells (for review, see References 3, 16, and 18). Displacement of white blood cells, which leads to changes in the number and composition of leukocytes in the peripheral blood, is the most commonly observed phenomenon.<sup>1,8,12</sup> Disturbances in granulocytes after either *in vivo* or *in vitro* irradiation have also been noted, for example, increased cell membrane permeability and injury to subcellular granules<sup>4</sup> and depression of phagocytic function,<sup>14,19</sup> with inhibition of intracellular killing of bacteria.<sup>4</sup> Rabbits irradiated with low power densities of 3-GHz microwaves for a few months exhibit a functional diminishing of granulopoietic reactivity to stimulating agents, which is manifested by a reduced bone marrow granulocyte reserve pool.<sup>20</sup>

The above observations all suggest that the granulocyte system may react in a different manner to acute bacterial infections in animals exposed for a long time to nonthermal power densities of microwave radiation, because granulopoiesis occurs rapidly after such infections.<sup>12</sup> Functional tests of granulopoiesis, elaborated recently,<sup>8,11,12,17,19</sup> including reserve pool mobilization,<sup>9,11</sup> lysozyme activity in blood serum,<sup>7,10,19</sup> and reduction of nitro blue tetrazolium in peripheral blood granulocytes,<sup>1,8,17</sup> make possible a more precise evaluation of granulopoietic reaction to stimulating agents, such as acute bacterial infections.

The purpose of this investigation was to examine granulopoietic reaction in rabbits exposed for several weeks to microwave radiation concurrent with experimental acute staphylococcal infection.

#### MATERIALS AND METHODS

Ten adult rabbits were exposed in an anechoic chamber to 3-GHz (10 cm) electromagnetic waves generated from a 500-W magnetron. The animals were placed in far-field conditions (more than 180 cm in front of a conical antenna with a 20 × 30-cm base) and irradiated at 3 mW/cm<sup>2</sup> 6 hr daily. Five subjects were irradiated for 6 weeks; the remainder were so exposed for a total of 3 months. An additional five rabbits served as controls. After the treatment period, the animals were infected intravenously with virulent *Staphylococcus aureus* Yacherts (7 × 10<sup>6</sup> cells/kg body wt).

Before and 4, 6, 10, and 14 days after infection, the following functional tests of granulopoiesis were performed: leukocyte and granulocyte number in peripheral blood; bone marrow picture; reserve pool mobilization 6 hr after intravenous in-

\*Supported by Research Grant 05-327-2 from the United States Public Health Service.

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jection of 10  $\mu\text{g/kg}$  body weight of purified staphylococcal  $\alpha$ -toxin;<sup>20,21</sup> lysozyme activity in blood serum, lysis of resuspended lyophilized *Micrococcus lysodeikticus*; <sup>12</sup> nitro blue tetrazolium test in peripheral blood granulocytes. In the last test, heparinized venous blood was mixed with 2 mg/ml nitro blue tetrazolium (1:1) in isotonic phosphate buffer (pH 7.2), incubated for 30 min at 37°C, and slides were prepared. The percentage of reactive cells, as determined by blue formazan deposits, was calculated from slides counterstained with nuclear fast red.<sup>1,8,17</sup>

### RESULTS

In control animals, staphylococcal infection produced a rise in body temperature during Days 10–14. No lethal effects were observed. The number of leukocytes and granulocytes in peripheral blood was increased during the entire observation period (FIGURE 1). In the bone marrow, a higher percentage of young granulocytic cell forms (promyelocytes, myelocytes, and metamyelocytes) was found 10 and 14 days after infection.

The bone marrow granulocyte reserve pool after staphylococcal  $\alpha$ -toxin injection equalled 4160 cells/mm<sup>3</sup> in normal animals (increase of granulocyte number in peripheral blood 6 hr after injecting the toxin); this value increased to 5080 cells/mm<sup>3</sup> 4 days after infection and jumped further to 8210 cells/mm<sup>3</sup> 14 days after infection (FIGURE 2).

Lysozyme activity in normal animals was about 15.5  $\mu\text{g/ml}$ , and, after infection, high values, 93.6 and 82.4  $\mu\text{g/ml}$  after 4 and 6 days, respectively, were quickly reached. Ten and 14 days after infection, the lysozyme activity was still higher in infected than in healthy animals but lower than in the first stage of disease (FIGURE 3). Nitro blue tetrazolium reduction, manifested by blue formazan deposits, in

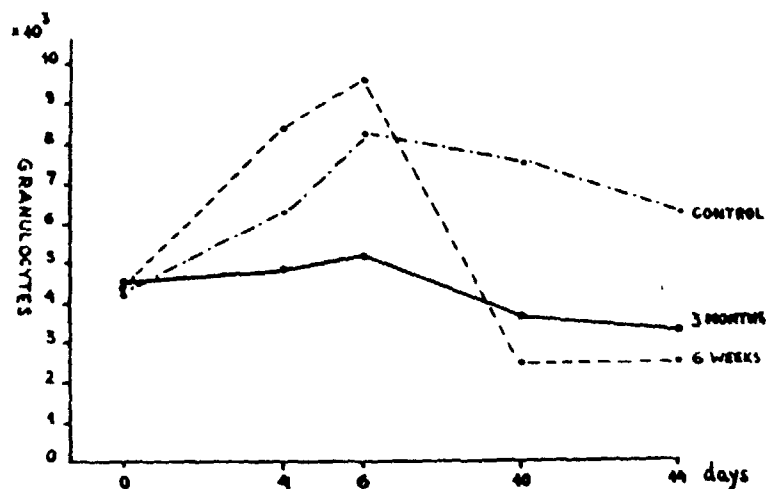


FIGURE 1. Granulocyte number in peripheral blood of rabbits irradiated with microwaves (6 weeks or 3 months) and infected with *S. aureus* Yacherts.

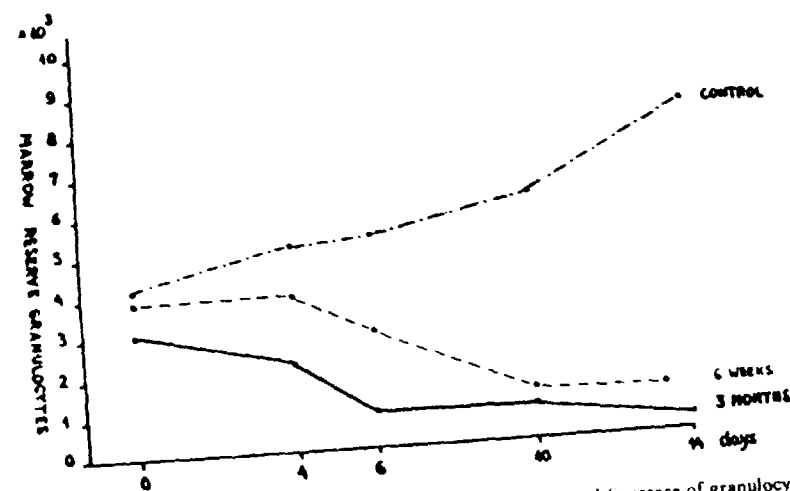


FIGURE 2. Mobilization of bone marrow granulocyte reserve pool (increase of granulocyte number in peripheral blood 6 hr after injection of purified staphylococcal  $\alpha$ -toxin) in rabbits exposed to microwaves (6 weeks or 3 months) and infected with *S. aureus* Yacherts.

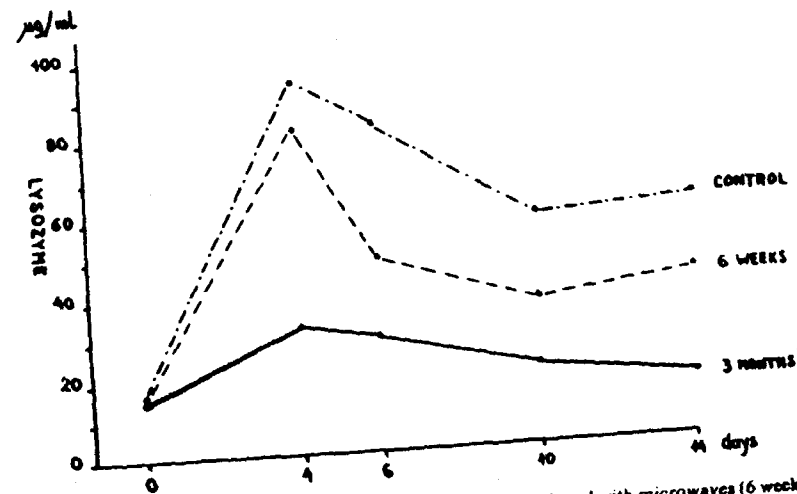


FIGURE 3. Lysozyme activity in blood serum of rabbits irradiated with microwaves (6 weeks or 3 months) and infected with *S. aureus* Yacherts.

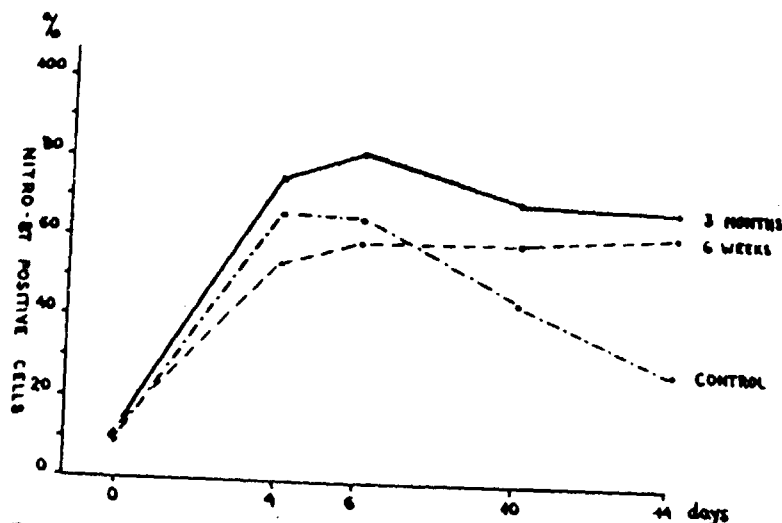


FIGURE 4. Percentage of nitro blue tetrazolium-reducing granulocytes in peripheral blood of rabbits exposed to microwaves (6 weeks or 3 months) and infected with *S. aureus* Yacherts.

normal animals was visible in about 10% of the granulocytes and increased dramatically 4 and 6 days after infection (FIGURE 4).

#### Irradiated Animals

Animals irradiated with microwaves for 6 weeks or 3 months exhibited no lethal effect as long as 14 days after staphylococcal infection, although, behaviorally, the exposed animals differed from controls, and the clinical course of disease was more serious. Granulopoietic reaction to staphylococcal infection also differed markedly from that observed in control animals.

Rabbits exposed to microwaves for 6 weeks displayed stronger leukocytosis and granulocytosis than did control animals 4 and 6 days after infection (FIGURE 1); these changes were followed by a dramatic drop below normal values 10 and 14 days after infection. These changes were accompanied by a decline in the bone marrow reserve pool (FIGURE 2) during the entire observation period and a lysozyme activity that was reduced from that seen in control animals infected with staphylococci (FIGURE 3). The percentage of granulocytes that reduced nitro blue tetrazolium was high during the whole observation period and it did not show any tendency to decrease, as was observed in the control group (FIGURE 4).

Animals exposed to microwaves for 3 months displayed markedly lower leukocytosis and granulocytosis after infection with staphylococci than did the controls, although before infection values approximately the same as in normal rabbits were found (FIGURE 1). In bone marrow 4, 10, and 14 days after infection, the percentage of mature granulocytes declined. This reduction led to a relative increase in the percentage of younger granulocytic cell forms (promyelocytes, myelocytes, and metamyelocytes).

The bone marrow granulocyte reserve pool was lowered during the entire post infection period (FIGURE 2), as compared to both controls and animals exposed to microwaves for 6 weeks. The blood serum lysozyme activity in animals irradiated for 3 months reached 32  $\mu\text{g/ml}$  on Day 4 after staphylococcal infection, whereas controls and rabbits treated for 6 weeks exhibited values of 93.6 and 81  $\mu\text{g/ml}$ , respectively. No further rise in such activity was observed in these animals (FIGURE 3). The percentage of nitro blue tetrazolium-reducing granulocytes in animals exposed for 3 months increased after staphylococcal infection to values close to those observed in controls and remained elevated during the entire observation period.

#### DISCUSSION

When *S. aureus* Yacherts, a coagulase-positive strain, pathogenic for rabbits and nonpathogenic for humans, is injected intravenously in a proper dosage, an acute infectious disease occurs and lasts for about 2 weeks. Later, acute symptoms disappear and abscesses develop in various organs, predominantly the kidneys. Lethal effects in rabbits are rare. The acute disease period is accompanied by a rapid and vigorous granulopoietic reaction, which causes liberation of the bone marrow granulocyte reserve pool, increased lysozyme activity in the blood serum, and an increased percentage of nitro blue tetrazolium-reducing granulocytes in the peripheral blood.<sup>8, 10, 17, 18, 21</sup>

The bone marrow granulocyte reserve pool is liberated in early stimulatory periods<sup>8, 11, 12</sup> and under normal circumstances is quickly regenerated by both stimulation of proliferation and shortening of granulocyte maturation time.<sup>18</sup> In acute infections that do not exhaust the adaptative efficiency of granulopoiesis, the bone marrow reserve pool remains high during the entire disease period, as was observed in control rabbits infected with staphylococci. Animals exposed to microwaves for 6 weeks prior to staphylococcal infection depleted their granulocyte reserves after about 6 days of disease and exhibited markedly lower values 10 and 14 days after infection, whereas rabbits exposed to microwaves for 3 months prior to infection showed lowered bone marrow reserve pools during the entire observation period. This result suggests that granulopoietic reaction to stimulating agents was quantitatively impaired, as has been previously shown by experiments with bacterial toxins.<sup>20</sup>

The percentage of granulocytes that reduced nitro blue tetrazolium was elevated both in control rabbits and in those exposed to microwaves for 6 weeks or 3 months. The only difference was a higher number of nitro blue tetrazolium-positive cells in the irradiated animals. Reduction of nitro blue tetrazolium in mature granulocytes is effected by stimulation of oxidative metabolism and the hexose monophosphate shunt<sup>1, 17</sup> and represents the ability for intracellular killing of bacteria and digestion of foreign material in granulocytes. Reduction of nitro blue tetrazolium may also be stimulated *in vitro*<sup>8, 17</sup> with bacteria or bacterial toxins. An increased percentage of nitro blue tetrazolium-reducing granulocytes in acute infections seems to be based on the same principle, and it may partially be a measure of the clinical course of the disease.<sup>17</sup> Stimulation of nitro blue tetrazolium reduction in granulocytes of animals treated with microwaves suggests that the cells react normally to the stimulating agents and that a lowering of their number rather than of their reactivity causes functional impairment of the whole system.

Increased lysozyme activity in acute infections seems to result from stimulation of granulopoietic kinetics,<sup>7, 10, 18</sup> because it is believed that the activity of this enzyme

is related to granulocyte turnover. The decline in lysozyme activity of animals exposed to microwaves prior to staphylococcal infection as compared to infected control rabbits seems to be caused by decreased granulocyte production in the bone marrow and a deficiency in the bone marrow granulocyte reserve pool.

In summary, we feel that exposure to small power density microwaves for several weeks results in decreased production of mature granulocytes in the bone marrow, although these cells in peripheral blood formed prior to such treatment react through normal stimulation of oxidative metabolism and intracellular digestion to bacteria and bacterial toxins. Under normal circumstances, granulocyte production in irradiated subjects permits maintenance of a proper level of granulocyte numbers in the peripheral blood (with a decreased reserve pool in bone marrow), and impaired reactivity of the entire system occurs only after the action of stimulatory agents.

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## DISCUSSION

DR. K. D. STRAUB: Have you studied the phagocytic capability of leukocytes in an *in vitro* preparation after irradiation?

DR. SZMIGIELSKI: No, we did not. However, others have described the depressed phagocytic function; for example, Mayers and Habeshaw published an article [*Int. J. Radiat. Biol.* 24 (5)] on this subject.

DR. J. WEST (*Armed Forces Radiobiology Research Institute, Bethesda, Md.*): Did you look at the myeloid:erythroid ratio in the bone marrows? Were there any changes related to the increase in circulating granulocytes? What was the ratio of immature granulocytes to immature erythrocytes in the bone marrow?

DR. SZMIGIELSKI: We looked at the ratio of mature to immature granulocytes only and found an indirect shift, but it depends on mobilization and liberation of reserve pools. We did not examine red to white cell ratios.

E180

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Geneva, 1993

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